Run2016 p+p 62 GeV Option: Double-Spin Asymmetry A_{LT} in Forward π^0 Production

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$$p^{\uparrow} + \vec{p} \longrightarrow \pi^0 + X$$

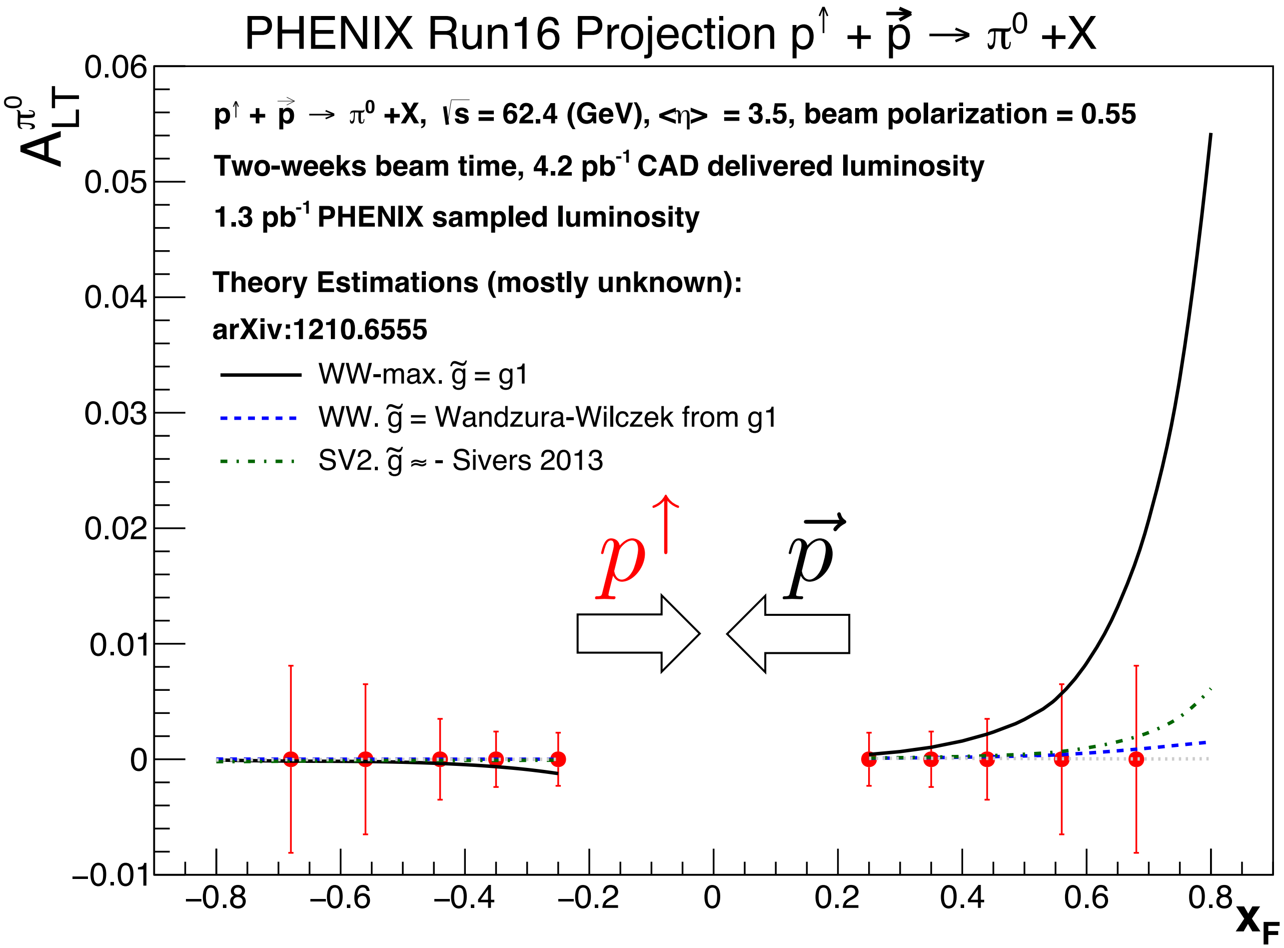
At RHIC, the world's only high energy polarized p+p collider, spin-asymmetries were measured on A_N A_{LL} A_{TT} A_L for hadrons, J/ψ, jet, $W^{\pm}$, etc. But never on A_{LT}

A straight forward measurement:

- RHIC can deliver: independently manipulate spin in each ring.
- PHENIX can measure: with MPC-EX/MPC, A_{LT} same effort as in A_{LL}

Motivation of A_{LT}: adding a new independent spin-observable in p+p to access nucleon's transverse spin structure, clearly answer: **inside a transversely polarized nucleon, could partons response differently to probes carrying opposite helicities ?** Either due to parton distributions (Metz, Pitonyak, Schaefer, Zhou, arXiv:1210.6555), or effects from parton fragmentation.

Discovery potential: first establish a non-zero asymmetry A_{LT} in p+p.



Based on ppg135:

- MPC-EX/MPC similar performance as in Run6.
- Beam Polarization=0.55.
- Two-weeks of beam time. 2*2.1*0.31=**1.3 pb^{-1}** (scaled from Run6)

Asymmetry A_{LT} :

- $\cos(\Phi_{spin})$ dependency.
- Flip sign with beam-spin flip.

Many build-in cross-checks.

Discovery potential:
First establish a non-vanishing asymmetry A_{LT} in p+p.

Theory estimation (arXiv:1210.6555) considered parton distribution effects only, ignored effects from fragmentation. Also ignored three-parton correlation functions…

A_{LT} ~ [$\breve{g}(x_1)$+ off-diagonal 3parton-correlations $(x_1)]\odot\Delta g(x_2)$

No reason for A_{LT} to be zero

- Hard scattering factors can be large.
- Off-diagonal 3-parton correlation functions can be large.
- Effect from fragmentation can be large, just like in A_N.

arXiv:1210.6555, only considered effects from parton distributions:

$$\frac{P_h^0 d\sigma(\vec{S}_\perp, \Lambda)}{d^3\vec{P}_h} = -\frac{2\alpha_s^2 M}{S}\vec{P}_{h\perp}\cdot\vec{S}_\perp\,\Lambda\sum_i\sum_{a,b,c}\int_{z_{min}}^1\frac{dz}{z^2}D_1^{C/c}(z)\int_{x'_{min}}^1\frac{dx'}{x'}\frac{1}{x'S+T/z}\frac{1}{z\,\hat{m}_i}g_1^b(x')\frac{1}{x}$$

$$\times\left\{\left[\tilde{g}^a(x) - x\frac{d\tilde{g}^a(x)}{dx}\right]H_{\tilde{g}}^i + x\,g_T^a(x)\,H_{1,G_{DT}}^i + \frac{x}{2}\left(g_1^a(x) - g_T^a(x)\right)H_{3,G_{DT}}^i\right.$$
$$\left. + \int dx_1\frac{1}{1-\xi}\underbrace{\left[G_{DT}^a(x,x_1) + F_{DT}^a(x,x_1)\right]}_{\text{Ignored. Off-diagonal three-parton-correlation functions}}H_{2,G_{DT}}^i\right\} \tag{9}$$

Estimated

Based on spin structure function $g_1(x)$

Ignored.

Off-diagonal three-parton-correlation functions

No reason for A_{LT} to be zero

- Hard scattering factors can be large.
- Off-diagonal 3-parton correlation functions can be large.
- Effect from fragmentation can be large, just like in A_N.

MOTIVATION

- **Numerical results for A_{LT}** are based **only on (1 part of) the distribution term** (without the inclusion of genuine quark-gluon-quark correlators) and include **some inputs that are not well-constrained**

- One cannot rule out **large contributions from fragmentation effects (cf. A_N where now it is believed such effects dominate the asymmetry!** (Kanazawa, et al. PRD(RC) (2014)))

- A_N , A_{LL} , A_{TT} have all been measured at RHIC -> **Why not A_{LT} ? (RHIC is the only facility that can do it!)**

WHAT WE LEARN

- A **nonzero A_{LT}** might indicate that **fragmentation effects are crucial** to understanding twist-3 proton-proton spin asymmetries (like A_N), which is a **relatively recent development**

- This would **push theorists** to look into this feature more closely -> **for A_{LT} the studies are limited** and have not analyzed any fragmentation effects

- A **nonzero A_{LT}** could also give insight into relatively unknown **quark-gluon-quark correlations in the proton** that are crucial to the **evolution of the Qiu-Sterman function**

Motivation: **inside a transversely polarized nucleon, could partons response differently to probes carrying opposite helicities ?**

Non-zero A_{LT} in Semi-Inclusive DIS

Huang, *et. al.* PRL. 108, 052001 (2012) $\vec{e} + N^{\uparrow} \rightarrow e' + h + X$

Non-zero A_{LT} in Inclusive Hadron Production with a lepton probe

arXiv:1502.0139 $\vec{e} + N^{\uparrow} \rightarrow h + X$

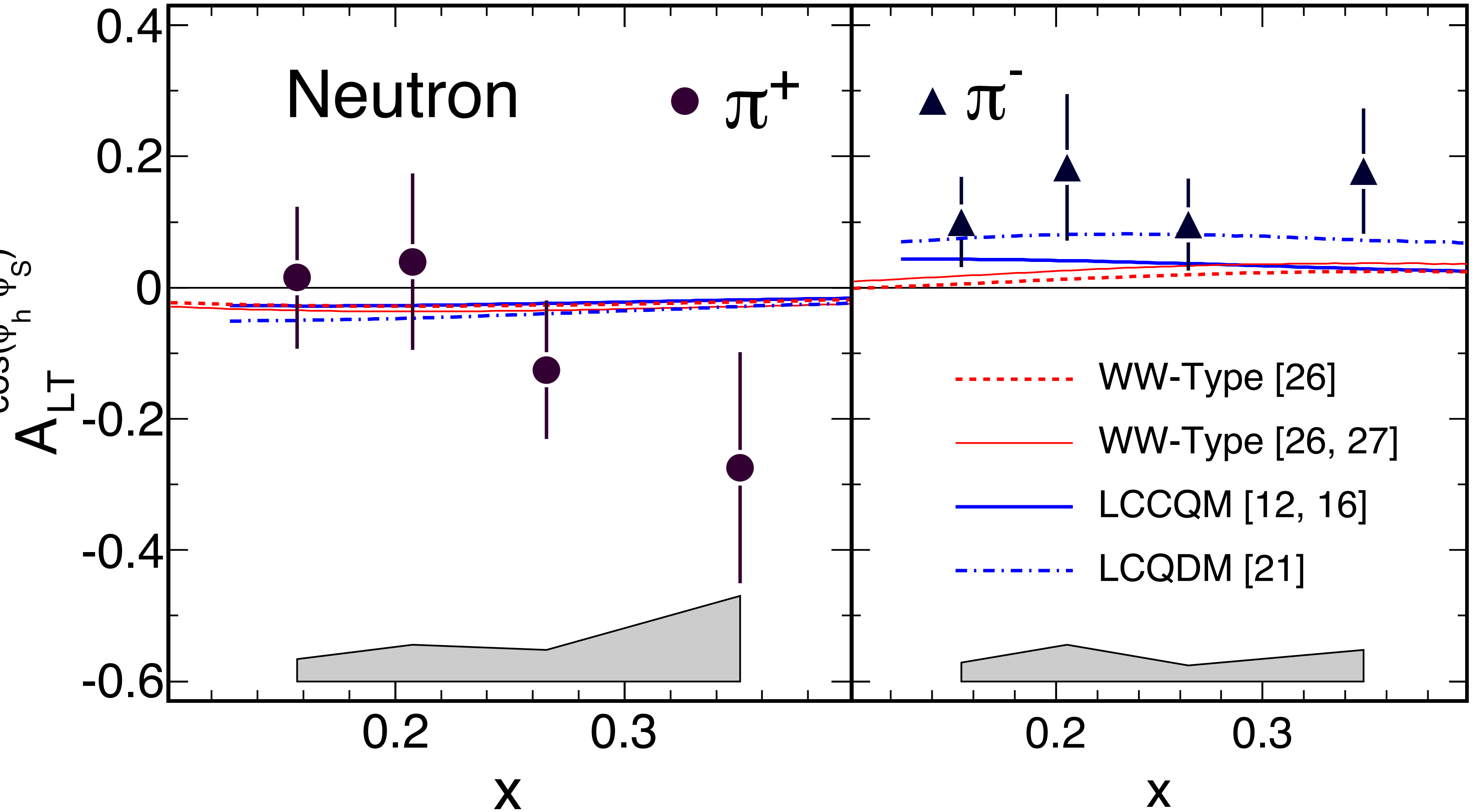
A non-zero A_{LT} in p+p has never been observed.

$$p^{\uparrow} + \vec{p} \longrightarrow \pi^0 + X$$

A non-zero A_{LT} will provide strong motivations for fsPHENIX, and shape new physics for EIC

Non-Zero A_{LT} in Semi-Inclusive DIS

$\vec{e} + N^{\uparrow} \rightarrow e' + h + X$ JLab E06010, J. Huang, *et. al.* PRL. 108, 052001 (2012)



- A non-vanishing quark "transversal helicity" distribution, reveals alignment of quark spin transverse to neutron spin direction

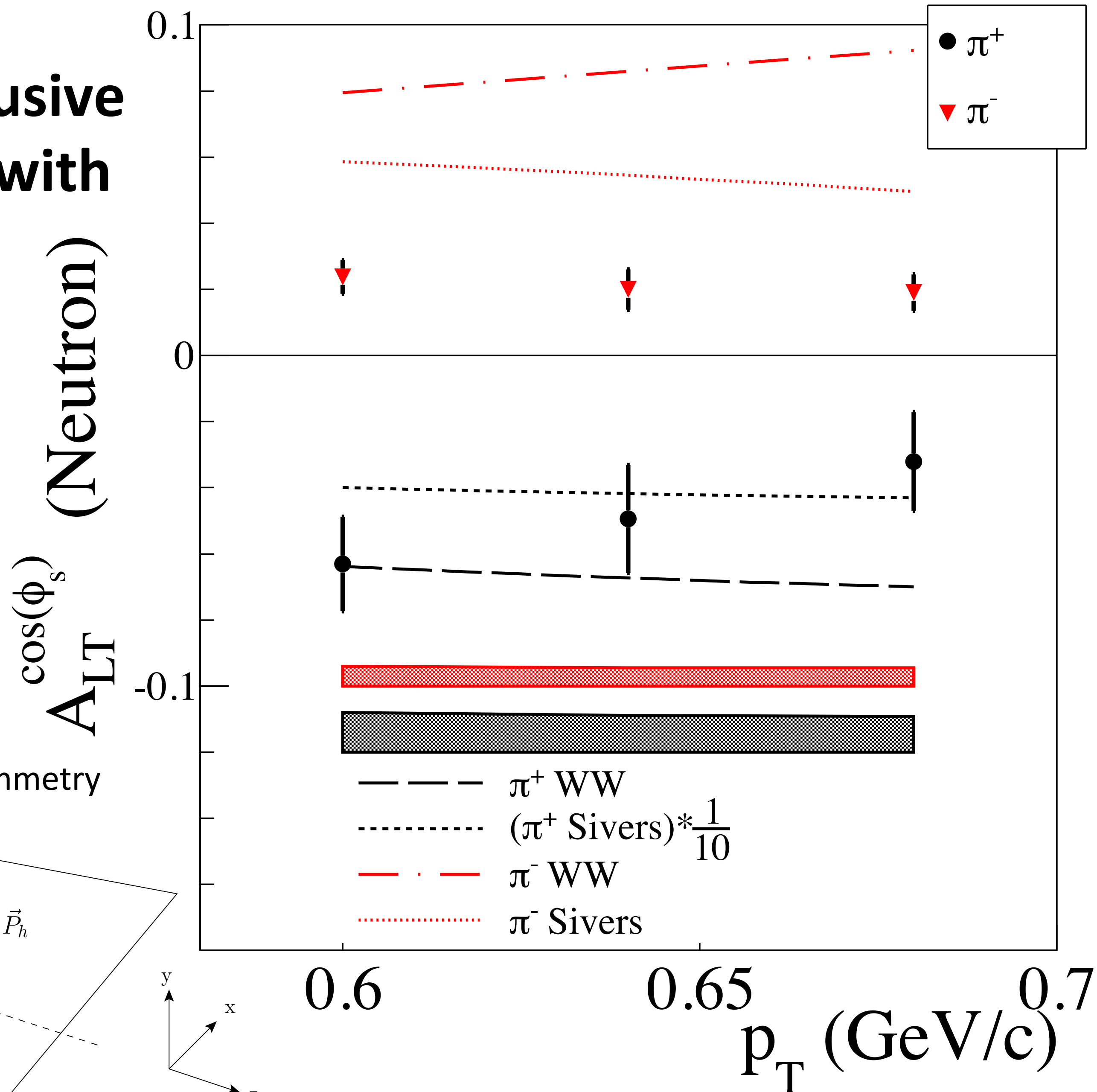
(HERMES observed a non-zero A_{LT} in SIDIS on a proton target)

Non-Zero A_{LT} in Inclusive Hadron Production with a Lepton Probe

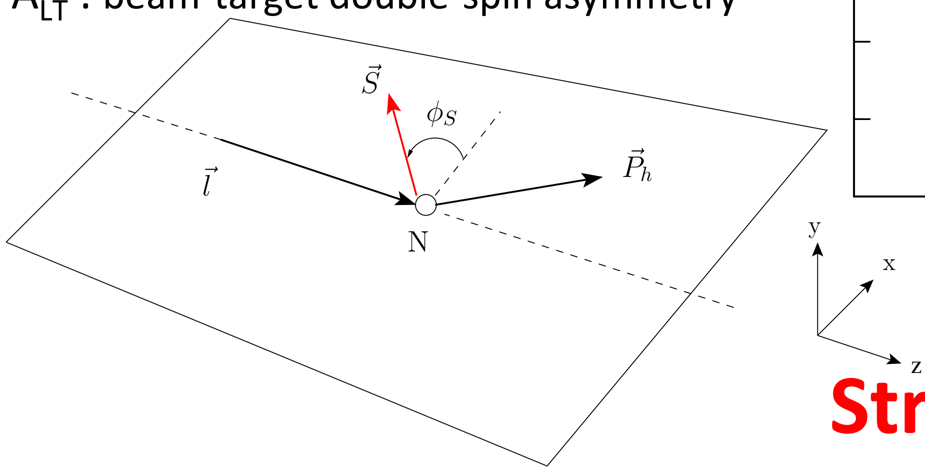
JLab E06010

Y. Zhao, et al, arXiv:1502.0139

$$\vec{e} + N^{\uparrow} \rightarrow h + X$$



A_{LT} : beam-target double-spin asymmetry



Strong Flavor Dependency !

Backup Slides

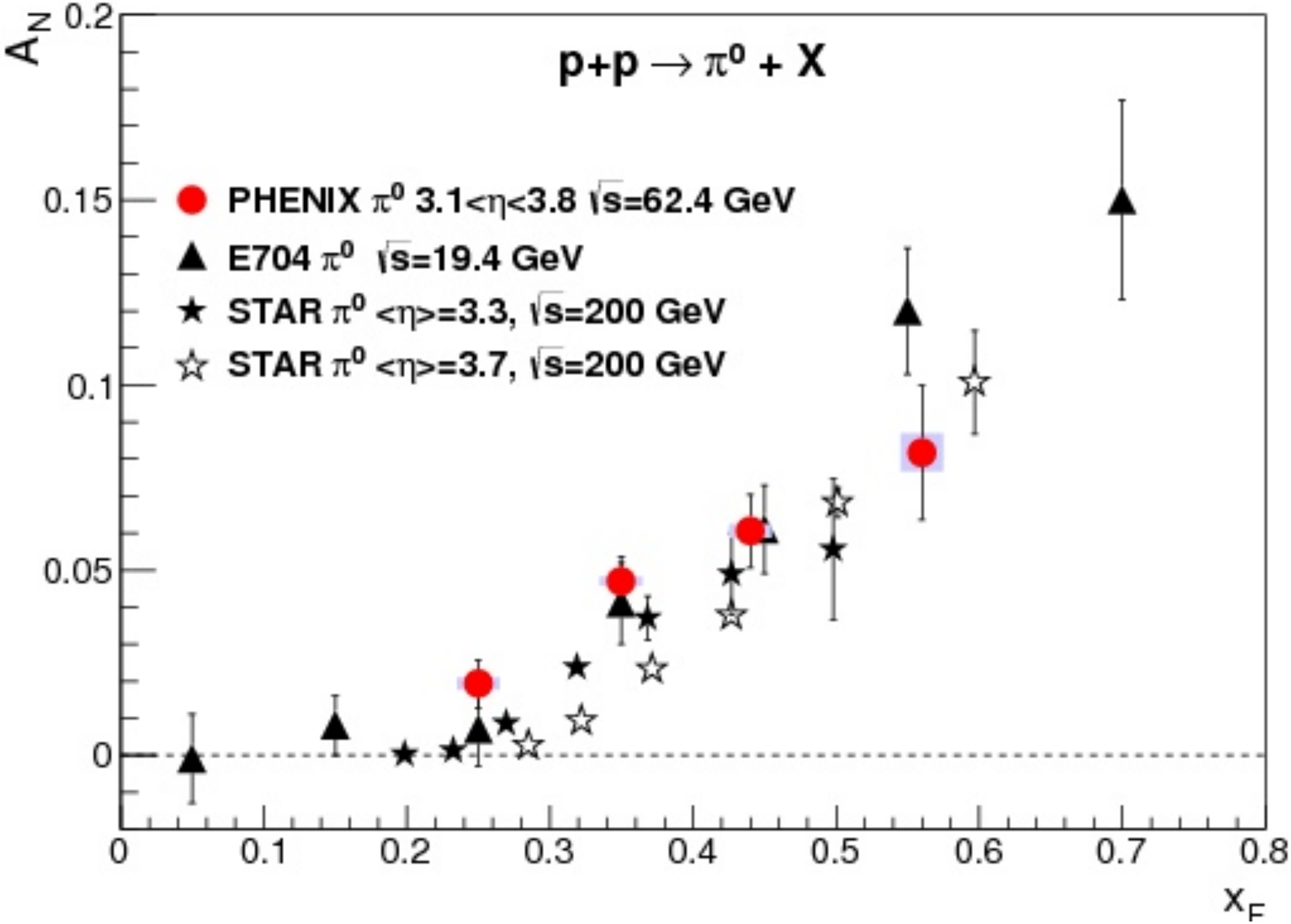
Questions Raised and Our Answers

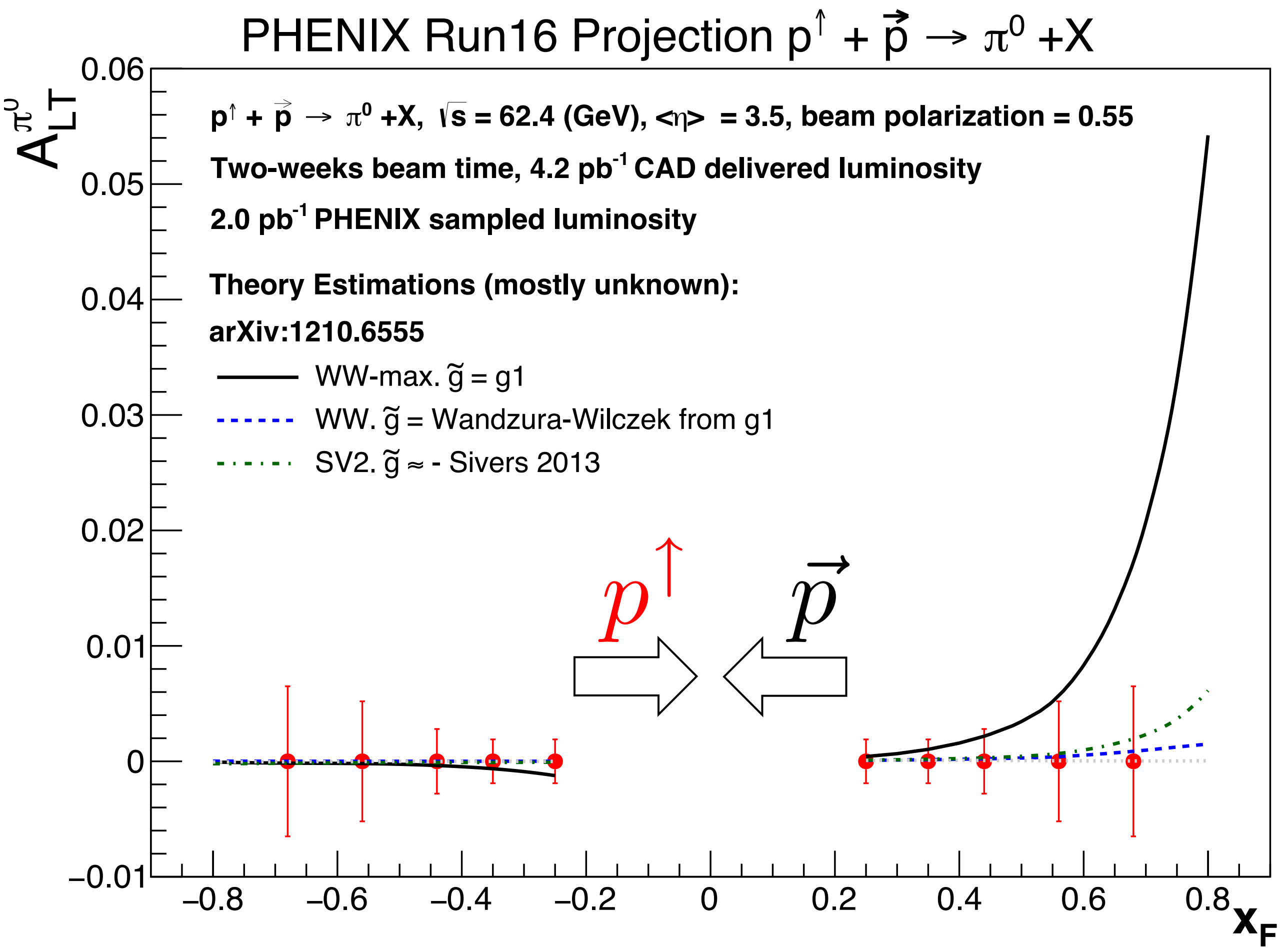
Q: We've already measure AN, and cos(\phi_spin) moment was looked, would existing data already tell you that ALT is small ?
A: No. Single-spin and double-spin asymmetry measurements probe completely different pieces of spin-dependent cross section.

Q: We know ALL is small, almost zero, ALT could only be smaller than ALL, right ?
A: No. mechanism of generating asymmetries could be very different, see page-4.

Q: Even theorists could not tell you what goes into this asymmetry ALT, why should we bother to measure it ?
A: That's exactly the reason we earn a living as experimentalists, we discover new phenomena that theorists have not predicted yet.

Of Course, improve A_N of π^0 and η (by x5)





sampled lumi=2.0 pb^{-1}

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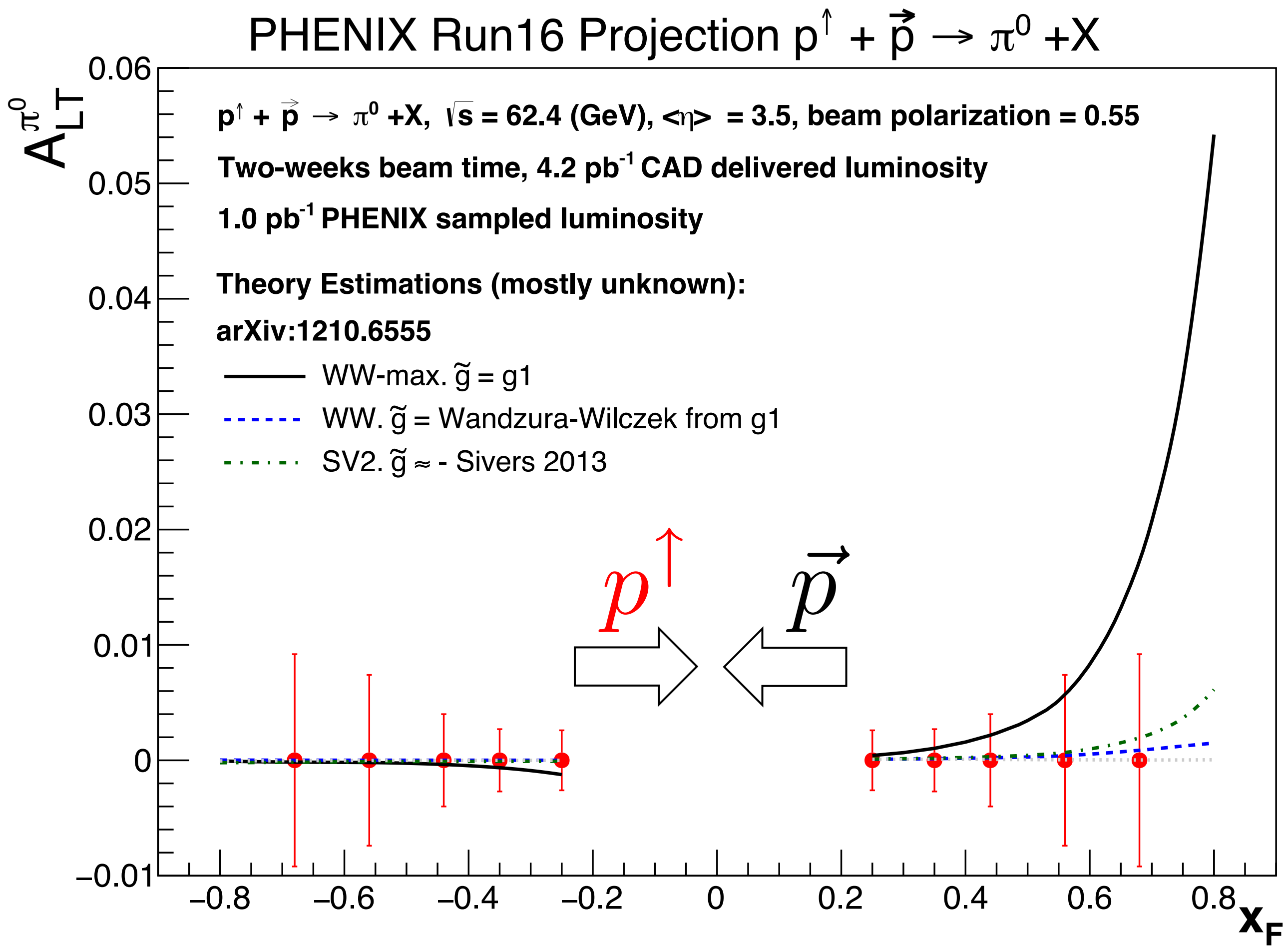

sampled lumi=1.0 pb^{-1}

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Experiment Goals and delivered/recorded luminosities (~final)

			Goal			Actual		
Exp	**pp �s energy**	**Pol**	**% Pol**	**Recorded L**	**Delivered L**	**Recorded L**	**Delivered L**	
				pb^{-1}	**pb^{-1}**	**pb^{-1}**	**pb^{-1}**	
PHENIX	200 GeV	R	50%	4-7	10-17	3.1	14.4	
	200 GeV	L	60%	10	30	7.5	31.1	
	62.4 GeV	T	50%			.025	0.16	**
	62.4 GeV	L	50%	0.6	1.4	.075	0.24	**
STAR	200 GeV	T	50%	3	15	3.34	18.9	
	200 GeV	L part 1##				2.1	7.87	
		L part 2				6.39	19.4	
		L total	50%	10	30	8.49	27.3	
	62.4 GeV	T	50%	0.5	1.5	.084	0.34	**
BRAHMS	62.4 GeV	T	50%	0.85	1.4	0.21	0.36	#

Run6
Phenix-recorded/
CAD-delivered = 0.31

			Actual	FOM Goal		FOM Actual		
Exp	**pp $^{\sqrt{}}$s energy**	**Pol**	**Average Pol**	**Recorded L**	**Delivered L**	**Recorded L**		**Delivered L**
				pb^{-1}	**pb^{-1}**	**pb^{-1}**		**pb^{-1}**
PHENIX	200 GeV	R	52.9%	1-1.8	2.5-4.3	0.87	*	4.03
	200 GeV	L	60.5%	1.3	3.9	1.00	*	4.19
	62.4 GeV	T	49.8%	N/A	N/A	0.0062	*	0.039
	62.4 GeV	L	47.5%	0.04	0.09	0.0038	*	0.012
STAR	200 GeV	T	57.6%	0.8	3.8	1.11	*	6.25
	200 GeV	L part 1##	51.8%			0.15	*	0.57
		L part 2	61.2%			0.90	*	2.72
		L total	59.0%	0.6	1.9	1.03	*	3.30
	62.4 GeV	T	48.3%	0.03	0.38	0.020		0.079
BRAHMS	62.4 GeV	T	48.2%	0.21	0.35	0.049	*	0.083

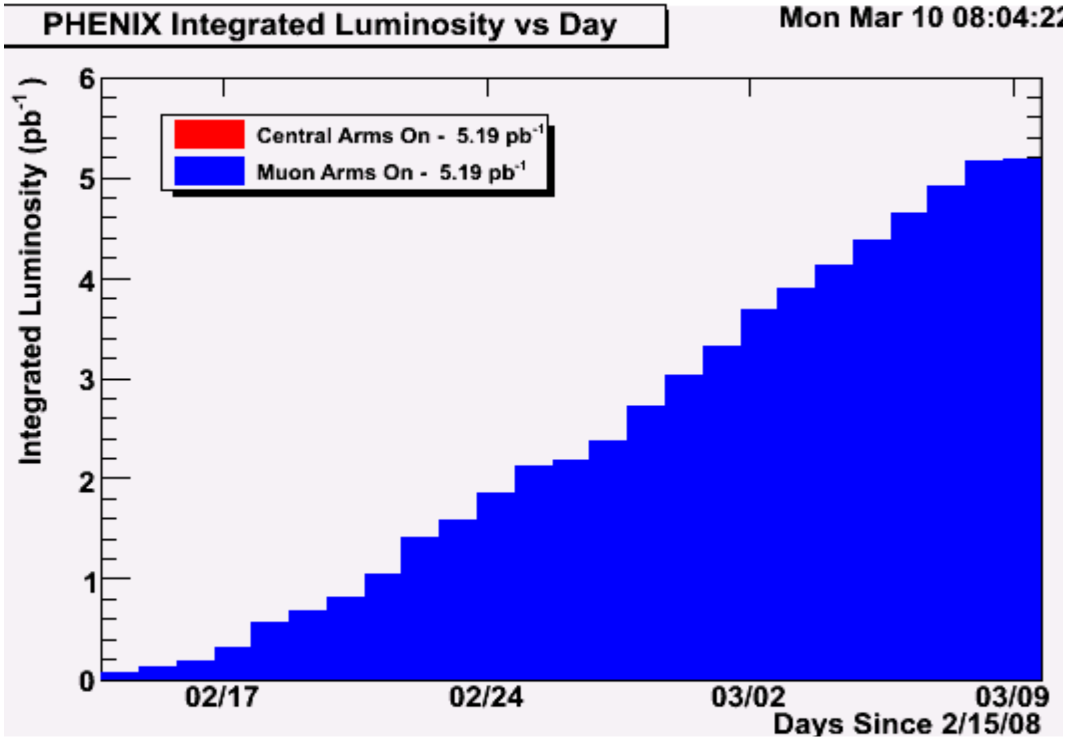
* ppile estimate from PHENIX and STAR input
** missing first physics store 7998 (estimated)
\# assumes BRAHMS Lumi 1.05 x STAR for stores through 12 June
\#\# taken during STAR tune-up phase

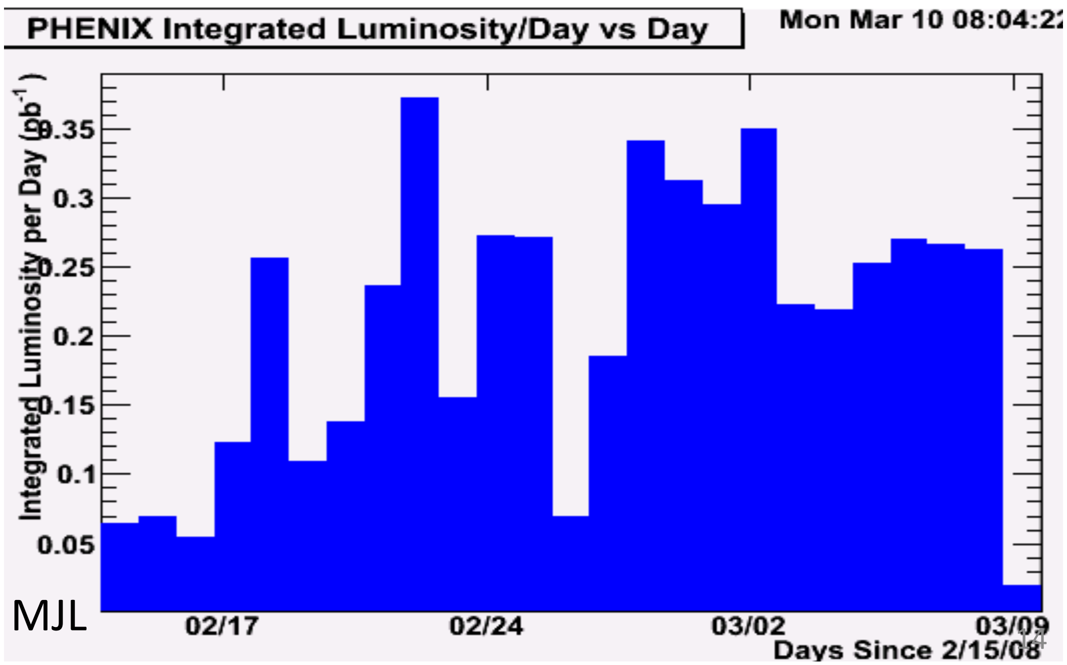
PHENIX's record, Mike Leitch

5.2 pb^{-1} 200 GeV p+p Transverse Vertical luminosity recorded (1.1 pb^{-1} FOM)

Peak luminosity per day ~0.37 pb^{-1}

Run	Energy	Long.	Trans.
02	200 GeV		0.15 pb^{-1}
03	200 GeV	0.35 pb^{-1}	
04	200 GeV	0.12 pb^{-1}	
05	200 GeV	3.4 pb^{-1}	0.16 pb^{-1}
06	200 GeV	7.5 pb^{-1}	2.7 pb^{-1}
06	62.4 GeV	0.08 pb^{-1}	0.02 pb^{-1}
08	200 GeV		5.1 pb^{-1}





ppg135 sampled luminosity=50 nb^{-1}

Table V: Transverse single spin asymmetries at √s=62.4 GeV as a function of x_F

	$\|x_F\|$	p_T	$A_N \pm \sigma_{stat} \pm \sigma_{syst} (x_F > 0)$	$A_N \pm \sigma_{stat} \pm \sigma_{syst} (x_F < 0)$
3.1 < |η| < 3.8	0.25	0.52	0.0193 ±0.0065 ±0.0017	−0.0067 ±0.0065 ±0.0017
3.1 < |η| < 3.8	0.35	0.71	0.0469 ±0.0067 ±0.0013	−0.0017 ±0.0066 ±0.0013
3.1 < |η| < 3.8	0.44	0.86	0.0605 ±0.0099 ±0.0019	−0.0182 ±0.0099 ±0.0019
3.1 < |η| < 3.8	0.56	1.01	0.0817 ±0.0182 ±0.0052	−0.0009 ±0.0181 ±0.0052

AnaNote1112, page-2, on Run6pp62 sampled luminosity:

The additional runs are in italics. There were a total of 663,137,869 "BBCLL1(noVertexCut)" live triggers. Assuming a cross-section of 14.3 ± 2.7 mb for the BBC triggered events, this means the data-set included in this analysis sampled an integrated luminosity of about 50/nb.

For sampled lumi=1.3 pb^{-1}, beam-polarization=0.55, each point on Run6 error bar

For A_{LT} reduce by \sqrt(1.3/0.050)*0.55=2.8

For A_N reduce by \sqrt(1.3/0.050)=5.1